A HYDRAULIC MODEL OF ARTERIAL SYSTEM FOR STUDY THE RELATIONSHIP BETWEEN BLOOD DISTRIBUTION AND FREQUENCY CHARACTERISTICS OF BLOOD PRESSURE WAVEFORM

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Abstract – **This paper was trying to find out a suitable hydraulic model for studying the frequency characteristics between blood pressure waveforms and systemic blood distribution. In the hydraulic model, the elastic tubes simulated the aorta and its major branches. The small balloons with different stiffness were used as organs. We used two kinds of tubes to test the hydraulic model and tried to find out suitable material to simulate the aorta and its major branches. We also used different volume of balloons to simulate the organs. The self-designed pump that could generate arbitrary pressure waves and pure sinusoidal waves was used to simulate the heart. For each different output waveforms of the pump, we measured the flow into each balloon by ultrasonic transducer and the pressure at the same sites by strain gauge transducer. Summary of the experiments showed that the latex tube was suitable material than silicon tube. In this way, this paper provides a framework for future efforts in hydraulic model and animal model experiments for the systemic circulation.**

Keywords – **Circulatory system, hydraulic model, pressure pump**

I. INTRODUCTION

This study was trying to find out a suitable hydraulic model to understand the relationship between arterial blood pressure and blood flow. We also wanted to emphasize on the relation between blood distribution and frequency characteristics of blood pressure waveforms.

We built an arterial model [1-2] and designed a pressure pump [3]. The arterial model was built with the elastic tubes to simulate the vessel and the balloons to simulate the organs. We used two kinds of tubes to simulate the vessels. The small balloons with different volume were to simulate the different organs. The pressure pump basing on a linear motor could accurately synchronize with an animal's heartbeats by using a phase-lock loop (PLL) technique. It has great flexibility and the ability to generate both arbitrary pressure waves and pure sinusoidal waves. We used the pressure pump to generate waves with different frequency components, and fed the waves into the arterial model. The experiment then observed the entrance flow of different sites in model.

II. METHODS

The whole study had two partial works. One was to build a hydraulic model of arterial system and the other was to design the pump. The arterial model was to simulate the vessel and the organs. We used two kinds of tubes to simulate the vessel and different volumes of balloons to simulate the different organs. In the hydraulic model, we used a network of elastic tubes to simulate the vessels and balloons attached to tubes end to simulate the organs. We divided the arterial model into eight segments and six balloons (Figure 1). Segment 1 and 2 were the aorta thoracalis. Segment 3 and 4 were the aorta abdominalis. Segment 5 was aorta coelica. Segment 6 was the aorta gastrica. Segment 7 was the aorta lienalis. Segment 8 was the aorta hepatica. Balloon 1 was the gastric. Balloon 2 was the splenic. Balloon 3 was the hepatic. Balloon 4 was the right renal. Balloon 5 was the left renal and superior mesenteric. Balloon 6 was the inferior mesenteric.

The pump was constructed using a synthesizer, a synchronizer, and a mechanical assembly. The synthesizer ran an inverse fast Fourier transform (IFFT), and synthesized the desired pressure wave. As most power of the blood pressure waveform is included in the first five harmonics [4], the desired pressure wave was determined by its first twenty harmonics. The module and the phase of the harmonics were input through the computer keyboard. The synthesized pattern was stored in random access memory (RAM) of 2048*12 bits. The RAM was roundly arranged with its output guided by an addressing counter. The addressing counter determined the output sequence of the RAM, and its initial value set the phase of the desired pressure wave. The value within the RAM was serially sent to a digital-to-analogue (D/A) converter, and an electric wave corresponding to the desired pressure wave was then generated.

The synchronizer used an animal's electrocardiograph (ECG) for time gating, and synchronized the pump with the animal's heartbeats. The mechanical assembly, converting the electric wave into the real pressure wave, consisted of a driving amplifier, a pump assemblage, and a reservoir.

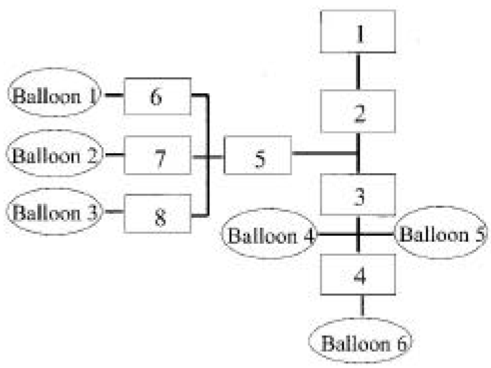

Fig. 1 the arterial model

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle A Hydraulic Model of Arterial System for Study the Relationship Between Blood Distribution and Frequency Characteristics of Blood Pressure Waveform	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Institute of Biomedical Engineering National Yang-Ming University Taiwan	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
2

III. RESULTS

The experiment showed that the latex tube was suitable to simulate the vessel than the silicon tube. The volumes of balloons were selected according to the size of organs.

In this study the performance of pump was considerate. The Bode plot (Figure 2) showed the pump had a flat frequency response up to 50 Hz. However, the response increased at 60 Hz.

The test of the square wave (Figure 3) showed an under damping response beginning at 60 Hz. This behavior was compatible with what the Bode plot indicated. The broad frequency response makes the pump generate the pressure waves to cover the heart rates of various animals, such as rats, rabbits, cats, and dogs. The upper frequency limit of 50 Hz is about the tenth harmonic of the rat's blood pressure.

The arterial model is suitable for studying the relation between blood distribution and the frequency characteristics of pressure. Using this model, we can realize how the flow distribution will be affected by the different frequency of pressure waves.

IV. CONCLUSIONS

This study had built a hydraulic model consisted of latex tubes and small balloons to simulate the vessel and organs. This study also designed a pump to generate pressure waves with accurate synchronization, great flexible and high fidelity. Accurate synchronization not only synchronizes the pump with the animal's heart beat-by-beat, but also couples the generated pressure waves to the animal's circulatory system with desired phase delay. Great flexibility makes the pump to generate the arbitrary pressure waves which are easily synthesized by the harmonics of blood pressure. High fidelity then ensures the generated pressure waves have minimal harmonic distortion.

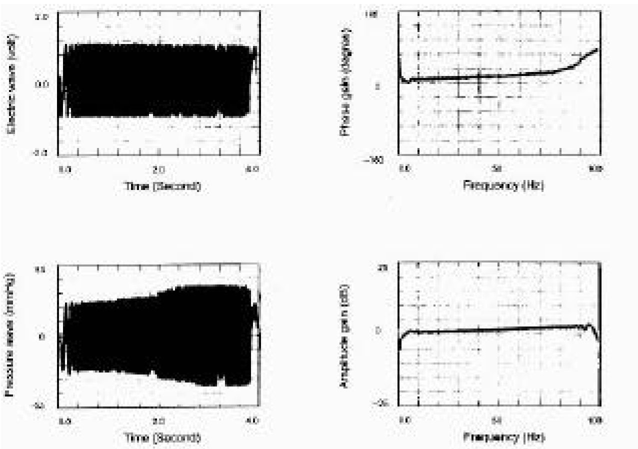

Fig 2 Bode plot of the frequency response of the pump having a flat frequency response up to 50 Hz. The frequency response has a rising gain beginning from 60 Hz.

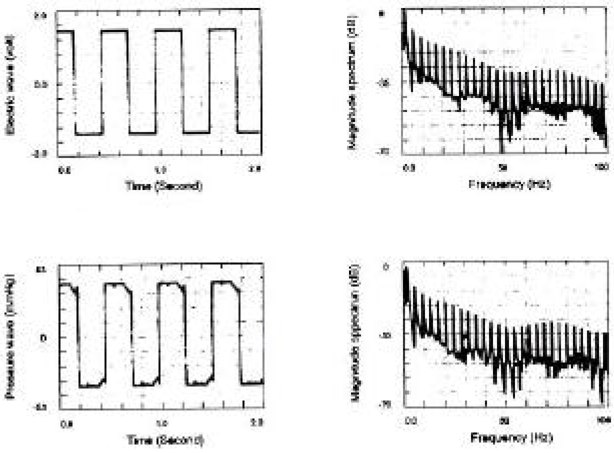

Fig. 3 Generated pressure waves of the pump responding to square electric waves. The under damping begins at the frequency of 60Hz

Such a pump is potentially suitable for the arterial model to verify how the flow distribution will be affected by the frequency of pressure waves.

REFERENCES

[1], W. K. Wang, Y. Y. Lo, Y. Chieng, T. L. Hsu, and Y.Y. Wang-Lin, " Resonance of Organs with the Heart," *Advance in Biomedical Engineering USA*, 1988

[2] S. T. Young, W.K. Wang, L. S. Chang, and T.S. Kuo, "Specific Frequency Properties of the Renal and the Supermesenteric Arterial Beds in Rat," *Cardiovasc. Res.*, vol. 23, no. 6, pp. 465-467, 1989.

[3] S. T. Young, Y. C. John, " A flexible pressure pump for cardiovascular studies," *Med. Eng. Phys.*, vol. 17, no. 4, pp. 243-247, 1995

[4], M. G. Taylor, " Use of random excitation and spectral analysis in the study of frequency-dependent parameters of the cardiovascular system," Circ. Res., vol. 18, pp. 585-95, 1966.